Town of Firestone, CO

Pavement Management Analysis Report

October 2014

Town of Firestone
Attn.: Theo Abkes, Director of Public Works
P.O. Box 100
Firestone, CO 80520

IMS Infrastructure Management Services
1820 West Drake Drive, Suite 108, Tempe, AZ 85283
Phone: (480) 839-4347, Fax: (480) 839-4348
www.ims-rst.com

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Abbreviation or Acronym	Definition
$k	Dollars in thousands ($,000)
$M	Dollars in millions
%SP	Percent Spreadability - component of deflection analysis
AC	Asphalt Concrete - asphalt streets, flexible pavements, also know n as ACP
ACP	Asphalt Concrete Pavement - asphalt streets, flexible pavements, also know n as AC
ART	Arterial roadw ay functional classification
ASTM	American Society of Testing Methods
Avg	Average
BCI	Base Curvature Index - component of deflection analysis
Brk	Break
CAL	Coarse Aggregate Loss
CDV	Corrected Deduct Value - part of the ASTM D6433 PCI calculation
COL	Collector roadw ay functional classification
Crk	Crack
DeflCON	Deflection Condition - structural load analysis based on traffoic loading and deflection
DMD	Dynamic Maximum Deflection - temperature corrected deflection
Dvdd Slab	Divided Slab
DynaCON	Dynamic Condition - structural layer analysis
ft or FT	Foot
ft2 or FT2	Square foot
FunCL	Functional Classification
FWD	Falling w eight deflectometer
GCI	Gravel Condition Index
GFP	Good - Fair - Poor
GIS	Geographic Information System
GISID	GIS segment identification number
H&V	Horizontal and Vertical
IRI	International Roughness Index
Jt	Joint
L&T	Longitudinal and Transverse
LAD	Load associated distress
LOC	Local roadw ay functional classification - same as RES
LOG	Lip of Gutter
m	metre or meter
M	Moderate
m2	square metre or square meter
MART	Major arterial roadw ay functional classification
Max	Maximum
MaxDV	Maximum Deduct Value
MCOL	Major collector roadw ay functional classification
mi or Mi	Mile
Min	Minimum
MnART	Minor arterial roadw ay functional classification
MnCOL	Minor collector roadw ay functional classification
MOD	Moderate
NLAD	Non-load associated distress
OCI	Overall condition index, also know n as PCI
Olay	Overlay
PART	Primary arterial roadw ay functional classification
Pavetype	Pavement Type
PCC	Portland Cement Concrete - concrete streets
PCI	Pavement Condition Index - generic term for OCI
R&R	Remove and replace
RART	Rural arterial roadw ay functional classification
Recon	Reconstruction
Rehab	Rehabilitation
RES	Local roadw ay functional classification - same as LOC
RI or RCI	Roughness Index
S	Strong
SART	Secondary arterial roadw ay functional classification
SCI	Surface Curvature Index - componenent of deflection analysis
SDI	Surface Distress Index
SI	Structural Index
STA	Station or chainage
Surf Trtmt	Surface Treatment
TDV	Total Deduct Value
W	Weak

1.0 PROJECT DESCRIPTION

1.1 PRINCIPLES OF PAVEMENT MANAGEMENT

Nationwide, billions of dollars have been invested in roadway networks by municipal, state and federal governments. Locally, the Town of Firestone has just over 25 miles of major roadways (arterials and collectors) and over 30 miles of local roadways, encompassing over 11.6 million square feet of asphalt and concrete surfacing. At an average replacement cost for a typical major roadway approaching $859K per mile – not including the value of the land, the Town has over $51 million invested in its paved roadway network.

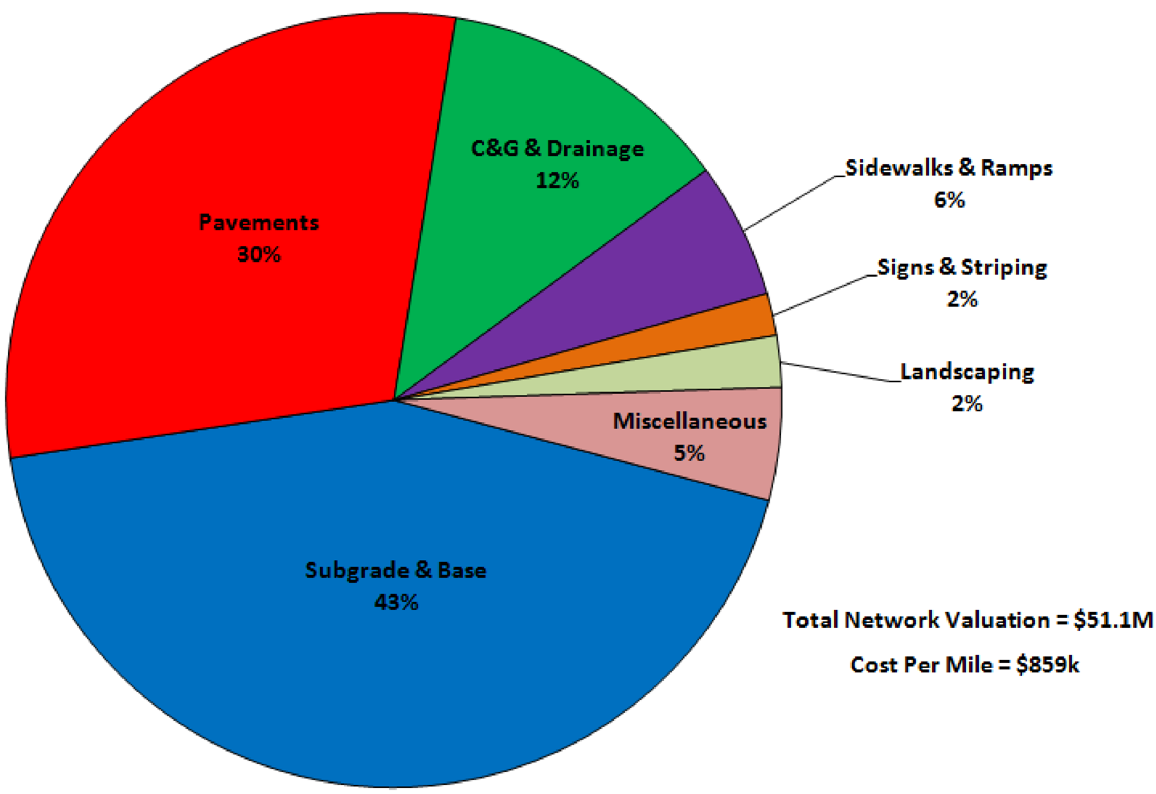

Figure 1 – Replacement Value of the Town of Firestone Paved Roadway Network

Preservation of existing roads and street systems has become a major activity for all levels of government. There is a shortage of funds to maintain street systems at the state and local government levels. Funds that have been designated for pavements must therefore be used as effectively as possible. One proven method to obtain maximum value of available funds is through the use of a pavement management system.

Pavement management is the process of planning, budgeting, funding, designing, constructing, monitoring, evaluating, maintaining, and rehabilitating the pavement network to provide maximum benefits with available funds.

A pavement management system is a set of tools or methods that assist decision makers in finding optimum strategies for providing and maintaining pavements in a serviceable condition over a given time period.

As shown in Figure 2, streets that are repaired when they are in a good condition will cost less over their lifetime than streets that are allowed to deteriorate to a poor condition. Without an adequate routine pavement maintenance program, streets require more frequent reconstruction, thereby costing millions of extra dollars. Over time, pavement quality drops until the pavement condition becomes unacceptable. For each street, the shape of the curve, and hence rate of deterioration, is dependent on many factors – foremost of which are the strength of the roadway structure and traffic loading. The key to a successful pavement management program is to develop a reasonably accurate performance model of the roadway, and then identify the optimal timing and rehabilitation strategy. The resultant benefit of this exercise is realized by the long term cost savings and increase in pavement quality over time. As illustrated in Figure 2, pavements typically deteriorate rapidly once they hit a specific threshold. A $1 investment after 40% lifespan is much more effective than deferring maintenance until heavier overlays or reconstruction is required just a few years later.

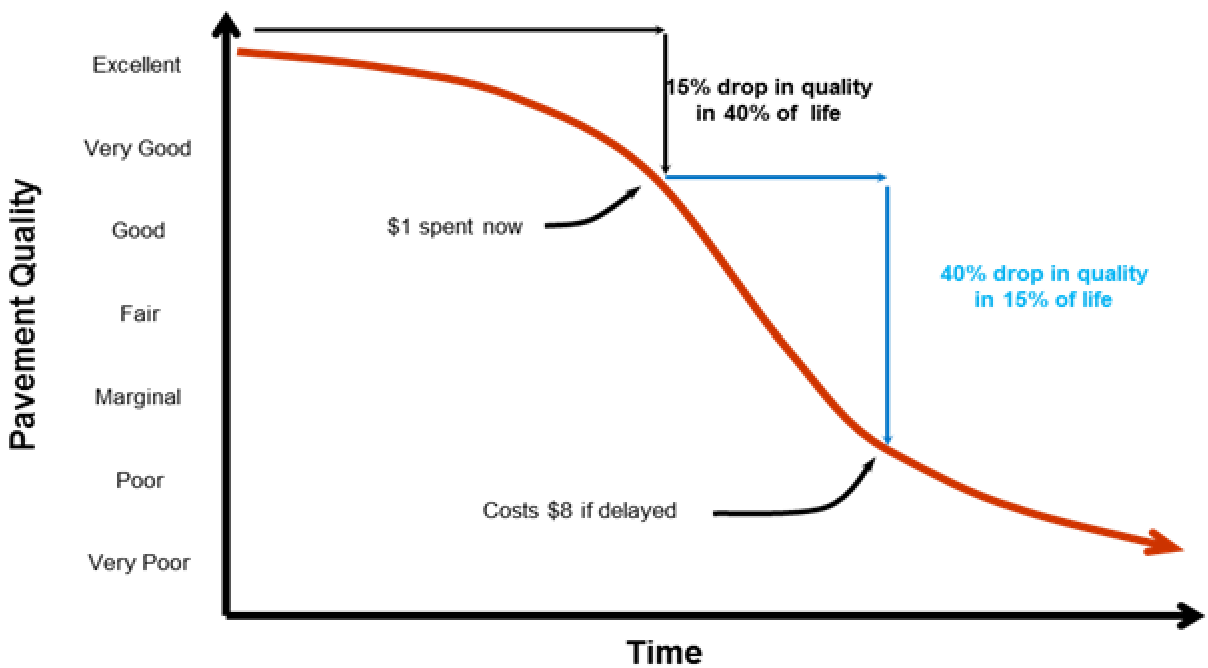

Figure 2 – Pavement Deterioration and Life Cycle Costs

Once implemented, an effective pavement information management system can assist agencies in developing long-term rehabilitation programs and budgets. The key is to develop policies and practices that delay the inevitable total reconstruction for as long as practical yet still remain within the target zone for cost effective rehabilitation. That is, as each roadway approaches the steep part of its deterioration curve, apply a remedy that extends the pavement life, at a minimum cost, thereby avoiding costly heavy overlays and reconstruction.

Thus, the goal of a pavement management system is to identify the optimal level of funding, timing, and renewal strategy that agencies should adopt to keep their roadway network at a satisfactory level of service. Figure 3 illustrates the concept of extending pavement life through the application of timely rehabilitations.

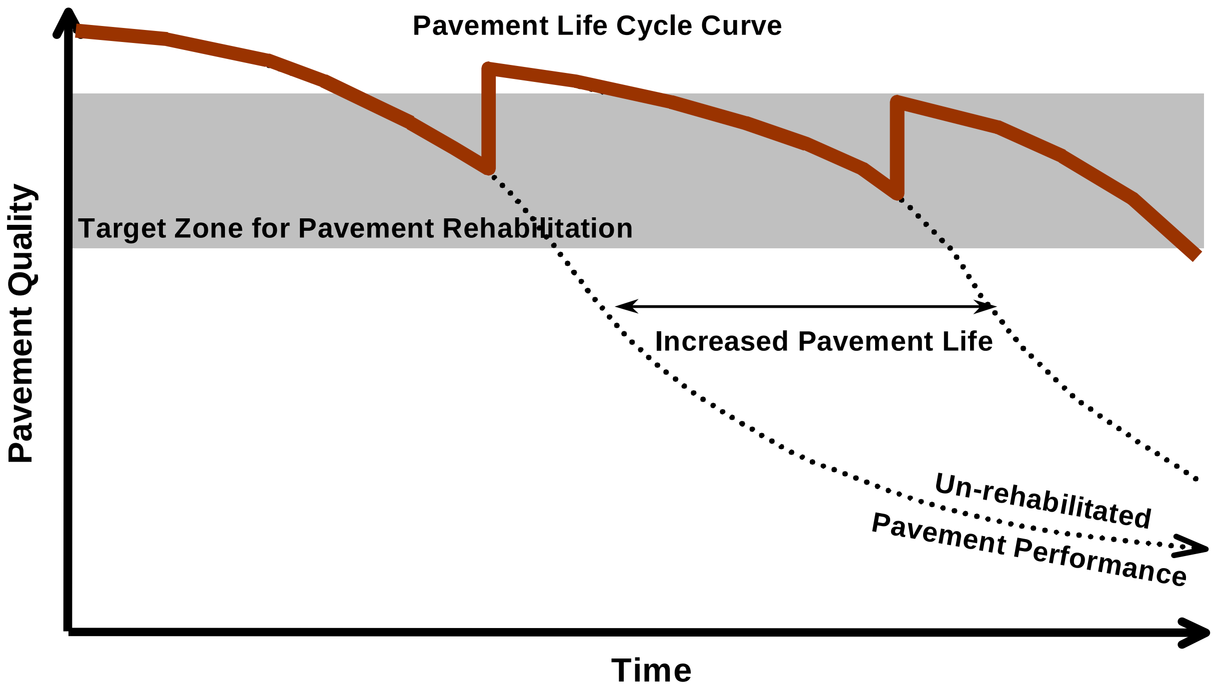

Figure 3 – Pavement Life Cycle Curve

Ideally, the lower limit of the target zone shown in Figure 3 would have a minimum value in the 60 to 70 range – that is to keep as many streets as possible requiring a thin overlay or less. The upper limit would tend to fall close to the higher end of the very good category – that is a pavement condition score approaching 85. Other functions of a pavement management system include assessing the effectiveness of maintenance activities, new technologies, and storing historical data and images.

For Firestone, a prioritization methodology based on pavement condition, pavement materials, condition and strength rating was used to analyze the network condition and develop the proposed 5 year rehabilitation plan.

The analysis methodologies and data collection technologies were based on the latest version of *ASTM D6433 Standard Practice for Roads and Parking Lots Pavement Condition Index Surveys* for assessment of pavement surface condition and the International Roughness Index (IRI) for quantification of pavement roughness on all town streets. Pavement strength was assessed using a Dynaflect device (non-destructive testing). These measurements of pavement quality are combined to form an overall 0 to 100 Pavement Condition Index (PCI), with 100 being the best.

1.2 THE PAVEMENT MANAGEMENT PROCESS

The actual pavement management process involves three unique, but important steps, and is presented graphically in Figure 4. Each activity builds on the previous, until the end result is a prioritized paving and rehabilitation program.

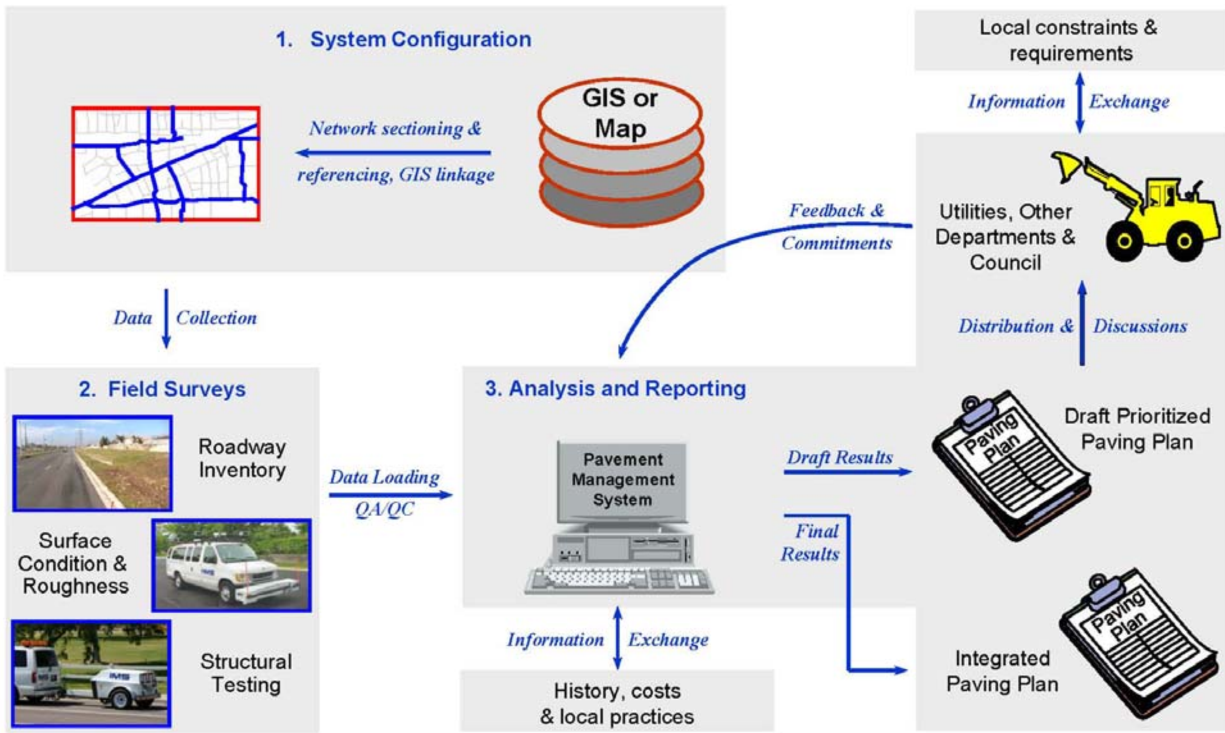

Figure 4 - The Pavement Management Process

Highlights of the pavement management process include:

1. **System Configuration** – This step involves identifying all roadways in the Town's network, assigning them a unique identifier, listing their physical characteristics (length, width, etc.) and demographic attributes (pavement type, traffic, functional classification), and linking the network to the Town's GIS map.

2. **Field Surveys** – Following a set of pre-defined assessment protocols matching the pavement management software (ASTM D6433), a specialized piece of survey equipment - referred to as a Laser Road Surface Tester (Laser RST, pictured on page 6), is used to collect observations on the condition of the pavement surface, as well as collect digital imagery and spatial coordinate information. The Laser RST surveys each street from end-to-end in a single pass, with arterial and collector roadways completed in two passes. In addition, a Dynaflect device was used to test the structural adequacy of roads.

   Key pavement condition data elements collected by the Laser RST include:

   - Roughness Index – Roughness is measured following the industry standard "International Roughness Index" (IRI). It is an open-ended score that measures the number of bumps per mile and reports the value as millimeters/meter. The IRI value is converted to a 0 to 100 score and reported as the Roughness Index (RI) as follows:

RI = (10.5 – 3.25 x ln(IRI)) x 10, where ln(IRI) is the natural logarithm of IRI.

In common terms, a newer street would have a Roughness Index above 85, while one due for an overlay would be in the range 40 to 75. Failed streets typically have roughness values below 40.

- Surface Distress Index – The Laser RST collects surface distress observations based on the extent and severity of distresses encountered along the length of the roadway following ASTM D6433 protocols for asphalt and concrete pavements. The surface distress condition (cracking, potholes, raveling and the like) is considered by the traveling public to be the most important aspect in assessing the overall pavement condition.

  Presented on a 0 to 100 scale, the Surface Distress Index (SDI) is an aggregation of the observed pavement defects. Within the SDI, not all distresses are weighted equally. Certain load associated distresses (caused by traffic loading), such as rutting or alligator cracking on asphalt streets, or divided slab on concrete streets, have a much higher impact on the surface distress index than non-load associated distresses such as raveling or patching. Even at low extents and moderate severity – less than 10% of the total area - load associated distresses can drop the SDI considerably. ASTM D6433 also has algorithms within it to correct for multiple or overlapping distresses within a segment.

  For this project, extent and severity observations were collected, processed and loaded into the pavement management system for the following distresses (listed in order from greatest to lowest impact). Within the software the distresses are presented as a 0 to 10 rating for review and reporting:

  Alligator Cracking – is quantified by the severity of the failure and number of square feet. Similar to rutting, alligator cracking, even at low extents can have a large impact on the condition score as this distress represents a failure of the underlying base materials.

  Wheel Path Rutting – starting at a minimum depth of ¼ inch, wheel path ruts are quantified by their depth and the number of square feet encountered. Even low densities of rutting can have a large impact on the final condition score.

  Longitudinal, Transverse, Block (Map) and Edge Cracks – are quantified by their length and width. Multiple longitudinal cracks that intertwine are the start of alligator cracking.

  Patching – Patching is quantified by the extent and quality of patches. When the majority of a roadway surface is covered by a patch – such as a large utility replacement, the rating of the patch is minimized. All potholes are rated as patches.

  Distortions – all uneven pavement surfaces such as depressions, bumps, sags, swells, heaves and corrugations are included as distortions and are quantified by the severity and extent of the affected area.

  Raveling – raveling is the loss of fine aggregate materials on the pavement surface and is measured by the severity and number of square feet affected.

Bleeding – is the presence of free asphalt on the roadway surface caused by too much asphalt in the pavement or insufficient voids in the matrix. The result is a pavement surface with low skid resistance and is measured by the amount and severity of the area.

Similar distresses were collected for concrete streets including divided slab, corner breaks, joint spalling, faulting, polished aggregate and scaling.

- Structural Index - The entire network of streets was also tested for structural adequacy using a Dynaflect device. The field data is then compared to what loads the road is expected to carry as well as used to develop a layer analysis to evaluate if the base materials and pavement structure are working as a single unit. The final result is a single 0 to 100 index value. Scores above a 75 indicate the pavement is structurally adequate, between a 45 and 75 indicate additional structure is required, while those below a 45 generally require replacement. On streets where no deflection testing was completed, the relationship between the final pavement condition score and amount of load associated distresses is used.

3. **Analysis and Reporting** – following the field surveys, the condition data is assembled to create a single score representing the overall condition of the pavement. The Pavement Condition Index (PCI) is calculated as follows:

PCI = 25% Roughness Index + 50% Surface Distress Index + 25% Structural Index

Analysis was completed using Firestone specific rehabilitation strategies, unit rates, priorities and pavement performance curves.

Laser Road Surface Tester (Laser RST)

1.3 UNDERSTANDING THE PAVEMENT CONDITION INDEX SCORE

The following illustration compares Pavement Condition Index (PCI) to commonly used descriptive terms. The divisions between the terms are not fixed, but are meant to reflect common perceptions of condition.

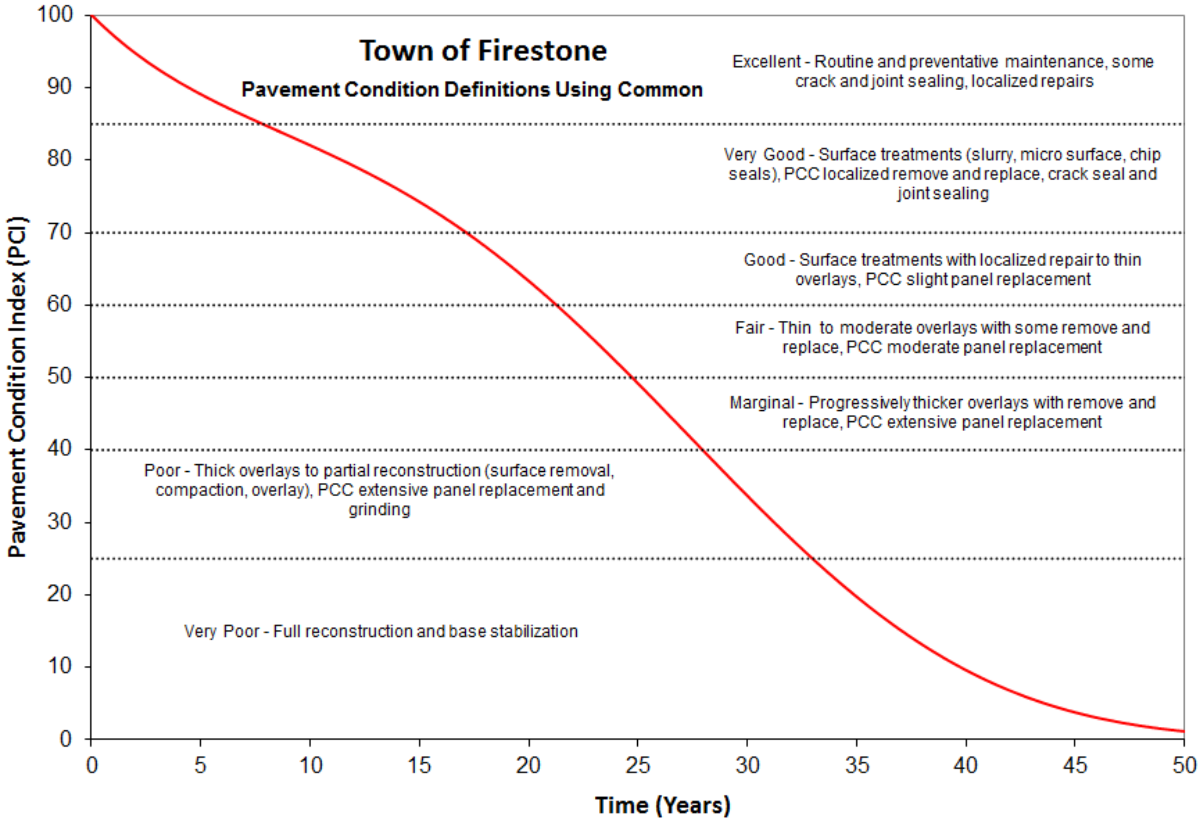

Figure 5 – Understanding the Pavement Condition Index (PCI) Score

The general idea of what these condition levels mean with respect to remaining life and typical rehabilitation actions is included in the following table:

PCI Range	Description	Relative Remaining Life	Definition
85 – 100	Excellent	15 to 25 Years	Like new condition – little to no maintenance required when new, routine maintenance such as crack and joint sealing.
70 – 85	Very Good	12 to 20 Years	Routine maintenance such as patching, crack sealing with surface treatments such as seal coats or slurries.
60 – 70	Good	10 to 15 Years	Heavier surface treatments and thin overlays. Localized panel replacements.
40 – 60	Fair to Marginal	7 to 12 Years	Heavy surface based inlays or overlays with localized repairs. Moderate to extensive panel replacements.
25 – 40	Poor	5 to 10 Years	Sections will require very thick overlays, surface replacement, base reconstruction and possible subgrade stabilization.
0 – 25	Very Poor	0 to 5 Years	High percentage of full reconstruction.

The images presented below provide a sampling of the Firestone streets that fall into the various condition categories with a discussion of potential rehabilitation strategies.

Very Poor (PCI = 0 to 25) – Complete Reconstruction

Ridge Rd. (Littleton, CO, PCI = 21) *– As no road segments were determined to be very poor in Firestone, an example of a very poor street in Littleton, CO is shown above. Rated as very poor, this street displays extensive base failure as evidenced by the severe amount of fatigue (alligator) cracking and wheel path rutting. A mill and overlay on this street would not be suitable as the base has failed and would not meet an extended service life of at least 15 years.*

Deferral of reconstruction of streets rated as very poor will not cause a substantial decrease in pavement quality as the streets have passed the opportunity for overlay based strategies. Due to the high cost of reconstruction, very poor streets are often deferred until full funding is available in favor of completing more streets that can be rehabilitated at lower costs, resulting in a greater net benefit to the town. This strategy however must be sensitive to citizen complaints forcing the street to be to be selected earlier. In addition, this type of street can pose a safety hazard for motorists, since severe potholes and distortions may develop. It is important to consistently monitor these streets and check for potholes or other structural deficiencies until the street is rebuilt.

Poor (PCI = 25 to 40) – Last Opportunity for Surface Base Rehabilitation

1st Street Buchanan Ave. to Monmouth Ave. (GISID 5, PCI = 34) *– Rated as Poor, this segment still has some remaining life before it becomes a critical reconstruction need. On this street, the base is starting to fail extensively and will continue to spread across the full width of the pavement. Some of the distresses present in this segment include linear & transverse cracking, alligator cracking, and rutting. However, if these areas were dug out and repaired, a mill and overlay would greatly extend the life of this roadway as the curb lines are in good condition and the base in reasonable condition.*

On arterial roadways, poor streets require full reconstruction – that is removal of the pavement surface and base down to the subgrade and rebuilding from there. On local roadways, they require removal of the pavement surface through grinding or excavation, base repairs, restoration of the curb line and drainage, and then placement of a new surface.

In general, the service life of poor streets is such that if deferred for too long, it would require a more costly reconstruction. Streets rated as poor are typically selected first for rehabilitation as they provide the greatest cost benefit to the Town – that is the greatest increase in life per rehabilitation dollar spent.

Marginal (PCI = 40 to 50) – Progressively Thicker Overlays, Often with Extensive Patching

***1st Street from Jackson Dr. to Wooster Ave. (GISID 9 , PCI = 43)** – Marginal streets have distresses that tend to be localized and moderate in nature – that is they do not extend the full length of the segment and can be readily dug out and repaired. This street segment highlights this characteristic as the failed area does not quite extend the full length or width of the roadway and is still serviceable. However, it also highlights the relationship between base and pavement quality. Placing an overlay on this street without repairing the base would not achieve a full 15 year life as the failure would continue to occur over time.*

Similar to streets rated as poor, marginal streets that display high amounts of load associated distresses are selected as a priority for rehabilitation as they provide the greatest cost benefit to the Town – that is the greatest increase in life per rehabilitation dollar spent. If left untreated, marginal streets, with high amounts of load associated distresses would deteriorate to become partial reconstruction candidates. Marginal streets that are failing due to materials issues or non-load associated failures may become suitable candidates for thick overlays if deferred without a significant cost increase.

Fair (PCI = 50 to 60) – Thin to Moderate Overlays

Wooster Ave. from 1st Street to 2nd Street (GISID 567, PCI = 57) *– rated in the Fair category, requiring thin to moderate overlays for asphalt and slab replacements for concrete when they enter their need year (generally within 2-3 points of the lower PCI in the defined range). Several distresses are present, but tend to be more localized and moderate in severity, and non-load related (primarily transverse shrinkage cracks). Asphalt streets rated as fair tend to receive a lower priority when developing a rehabilitation program. The reason for this is the cost to complete an overlay now would be on the order of $11 to $19/yd^2 depending on the functional classification. If deferred, the rehabilitation cost would only increase by about $3 to $6/yd^2 in about 5 to 10 years. Thus, the cost of deferral is low when compared to deferring a thick overlay to a reconstruction with a two to threefold increase in cost. Rehabilitation of concrete roads has limited options as it is difficult to complete surface based overlays. Rehabilitation strategies tend to focus on removal and replacement of whole or partial slabs and surface grinding to restore the longitudinal profile of the roadway.*

Good (PCI = 60 to 70) – Surface Treatments to Thin Overlays

Ruby Ave. from Cascade St. to Bluegrass St. (GISID 430, PCI = 68) *– rated as Good, it displays small amounts of distresses that can easily be removed, replaced, and covered to restore the visual appearance of the roadway.*

Streets rated as good are ideal candidates for thinner surface based rehabilitations and local repairs. Depending on the amount of localized failures, a thin edge mill and overlay, or possibly a surface treatment, would be a suitable rehabilitation strategy for streets rated as good. Streets that fall in the high 60 – low 70 PCI range provide the greatest opportunity for extending pavement life at the lowest possible cost, thus applying the principals of the perpetual life cycle approach to pavement maintenance.

Additional cost benefits of early intervention include:

- *Less use of non-renewable resources through thinner rehabilitation strategies.*
- *Less build-up of crown for the first and possibly second rehabilitation cycle.*
- *Less intrusive rehabilitation and easier to maintain access during construction.*
- *Easier to maintain existing drainage patterns*

Very Good (PCI = 70 to 85) – Surface Treatments and Routine Maintenance

McClure Ave. from Farmdale St. to Forest St. (GISID 387, PCI =79) *– rated as Very Good, displaying minor amounts of cracking that are localized and in good condition (this is about the worst part of the street). The ride is smooth, the surface is non-weathered, and the base is still strong.*

Streets rated as very good generally need lightweight surface based treatments such as surface seals, slurries, chip seals or micro surfacing. Routine maintenance such as crack sealing and localized repairs often precede surface treatments. The concept is to keep the cracks as waterproof as possible through crack sealing and the application of a surface treatment. By keeping water out of the base layers, the pavement life is extended without the need for thicker rehabilitations such as overlays or reconstruction. Surface treatments also tend to increase surface friction and visual appearance of the pavement surface but do not add structure or increase smoothness. Surface treatments may include:

- *Double or single application of slurry seals (slurries are a sand and asphalt cement mix).*
- *Micro surfacing – asphalt cement and up to 3/8 sand aggregate.*
- *Chip seals and Cape seals (Chip seal followed by a slurry)*

Excellent (PCI = 85 to 100)

Sage Ave. from Devonshire St. to Dogwood St. (GISID 334, PCI = 87) *- rated as Excellent, displaying little to no surface distresses. The ride is smooth and the surface is non-weathered and the base is still strong. In a couple of years, this street segment would be an ideal candidate for routine maintenance activities such as crack sealing.*

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2.0 ROADWAY NETWORK CONDITION AND FINDINGS

2.1 ROADWAY NETWORK SIZE

The paved roadway network consists of three functional classes, covering approximately 60 miles of pavement. The average pavement condition index (PCI) of the roadway network (asphalt and concrete) is 71. The network has two pavement types: asphalt and concrete, with asphalt being predominant. The following table and figure summarize the functional class splits within the system.

	Pavetype	Network	ART	COL	LOC
Segment (Block) Count	All Streets	608	120	109	379
	Asphalt	600	113	109	378
	Concrete	8	7	0	1
Length (mi)	All Streets	59.6	18.6	7.7	33.3
	Asphalt	58.8	17.9	7.7	33.2
	Concrete	0.7	0.7	0.0	0.1
Area (Ft2)	All Streets	11,589,892	3,908,898	1,497,220	6,183,774
	Asphalt	11,348,535	3,681,028	1,497,220	6,170,287
	Concrete	241,357	227,871	0	13,487

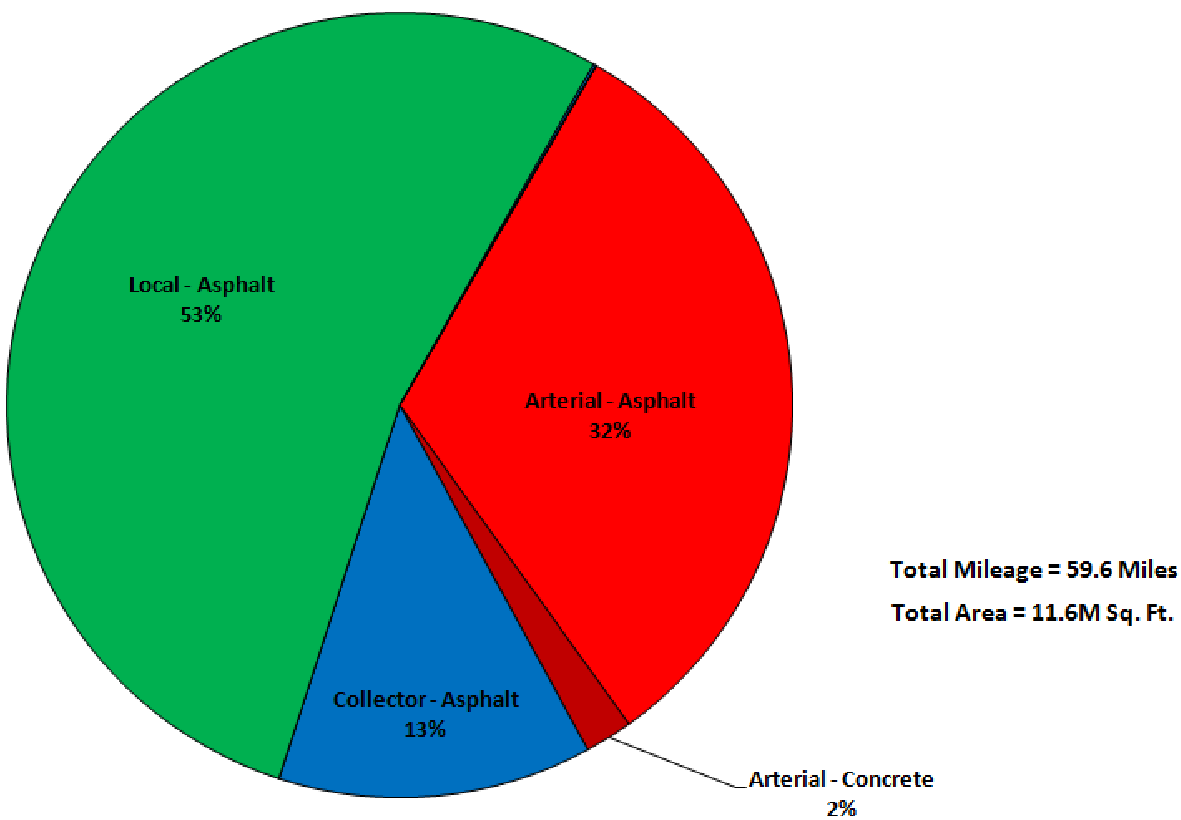

Figure 6 – Network Split by Functional Classification and Pavement Type

2.2 NETWORK PRESENT CONDITION

Figure 7 presented below shows distribution of pavement condition for the roadway network in the Town of Firestone on a 0 to 100 scale, 0 being worst and 100 being best condition. The average PCI for the network at the time of survey was 71, and is currently 70. While direct comparisons to other agencies is difficult due to variances in ratings systems, overall, Firestone is slightly above the average of agencies recently surveyed by IMS which typically fall in the 60 to 65 range.

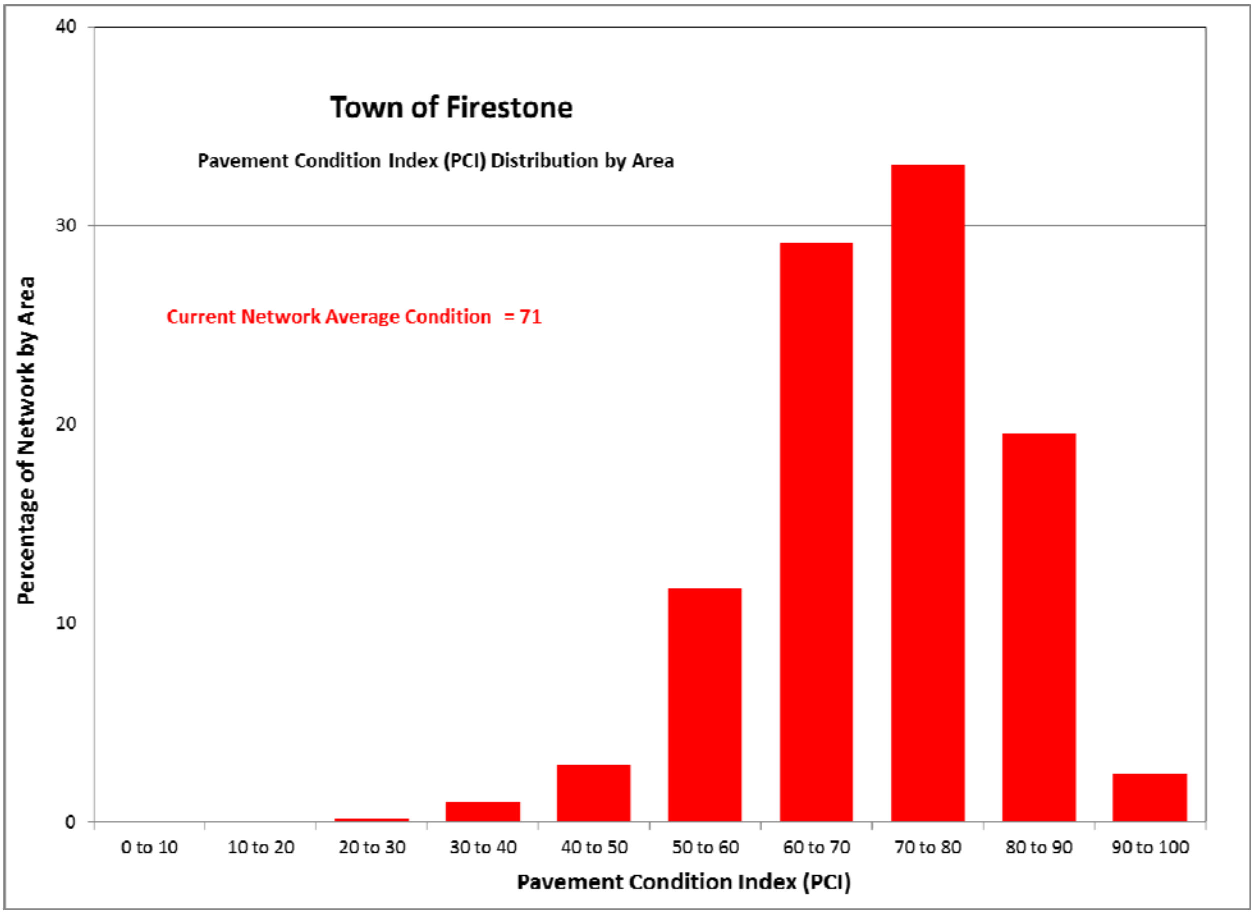

Figure 7 –Roadway Network Present Status

The current PCI distribution exhibits a moderately aged network that has been subject to a relatively effective crack sealing and patching program. However, many streets are approaching the end of their effective service life. Thus, while the network average PCI falls slightly above the typical range of similar cities, the amount of streets ready to fall into the reconstruct category over the next several years is a concern. However, it is good to note that there is a healthy amount of street with condition rating above 80, and the shape of the PCI distribution displays characteristics of a standard bell curve, so it gives the network a relatively good balance. Normal distributions generally reach their peak in the range of 60 to 70, and tend to taper off to the left.

The following graph (Figure 8) plots the same pavement condition information, but instead of using the actual Pavement Condition Index (PCI) value, descriptive terms are used to classify the roadways. From the chart, 12% of the network can be considered in excellent condition with a PCI score greater than 85.

These streets are in like new condition and require only routine maintenance. Nationwide, the amount of roadways falling into the excellent category is about 15%, so this value is slightly below the average.

Thirty-three percent (43%) of the network falls into the very good classification. These are roads that benefit most from preventative maintenance techniques such as microsurfacing, slurry seals and localized repairs. If left untreated, these roadways will drop in quality to become heavy surface treatment or overlay candidates.

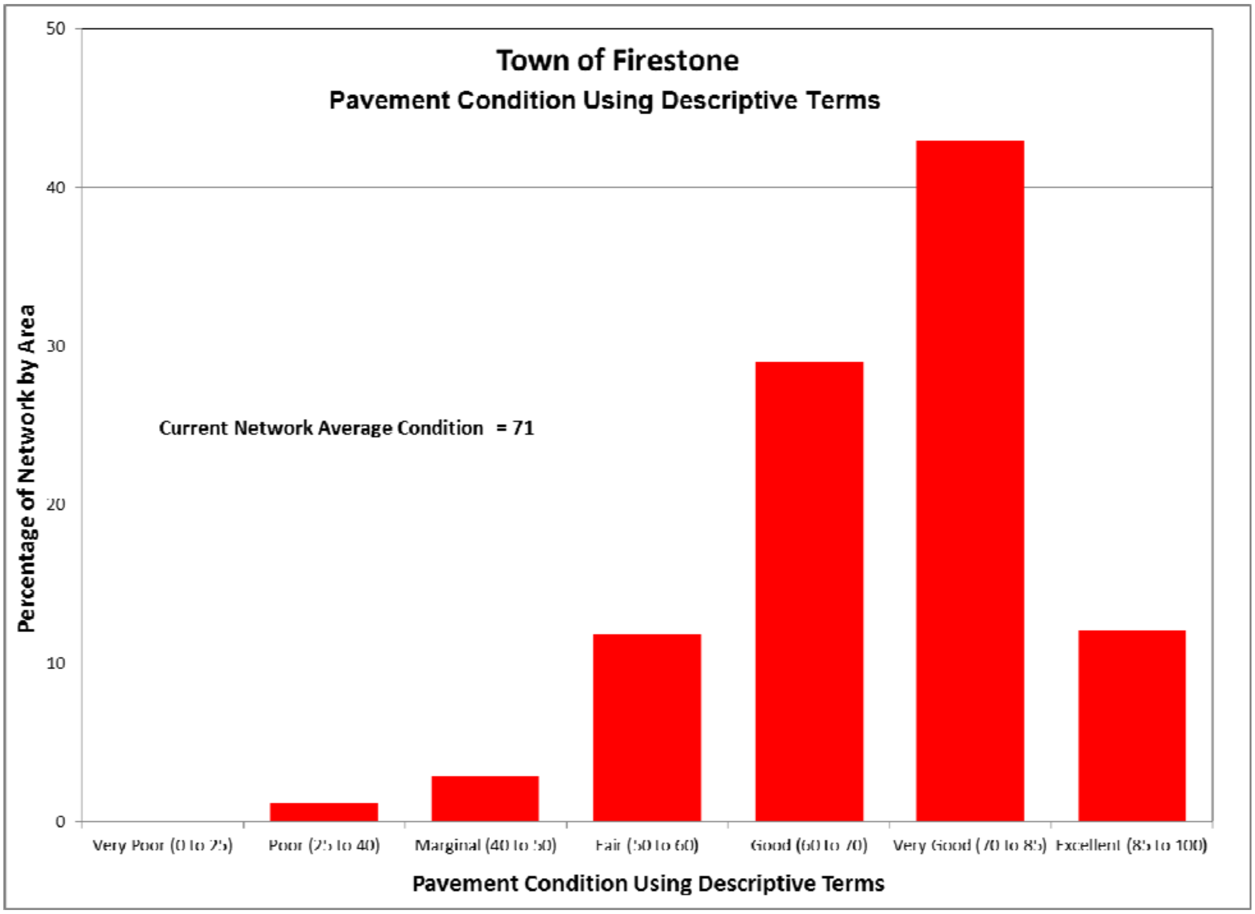

Figure 8 – Roadway Network Present Status Using Descriptive Terms

Thirty percent (29%) of the streets are rated as good – and are candidates for lighter surface based rehabilitations such as heavy microsurfacing or thin overlays. Sixteen percent (15%) of the network can be considered in fair to marginal condition, representing candidates for progressively thicker overlay based rehabilitation or panel replacements. If left untreated, they will decline rapidly into reconstruction candidates. The remaining 1% percent of the network (backlog) is rated as "poor" or "very poor", meaning these roadways have failed or are past their optimal due point for overlay or surface based rehabilitation and may require progressively heavier or thicker forms of rehabilitation (such as surface reconstruction or deep patch and paving) or total reconstruction.

Overall, the Town of Firestone has a solid network foundation. The majority of the network falls under the Very Good category, while the amount of Poor and Very Poor streets are minimal. Both of these performance measurements indicate a healthy pavement network.

2.3 STRUCTURAL AND LOAD ASSOCIATED DISTRESS ANALYSIS (ASPHALT ONLY)

Structural testing and analysis was completed on the roadway network using a Dynaflect device.

Dynaflects apply a known load to the pavement and measures the pavement response to the load through a series of geophones. From these results, the structural integrity of the roadway segment may be assessed. The purpose of the structural analysis is threefold, namely:

1. The results are used to identify and report sections with inadequate structural capacity by completing a layer analysis of the subgrade, base and pavement layers.
2. The structural index provides input into which performance curve each segment is to use - performance curves are used to predict pavement deterioration over time.
3. Assists in rehabilitation selection by constraining inadequate pavement sections from receiving too light of a rehab.

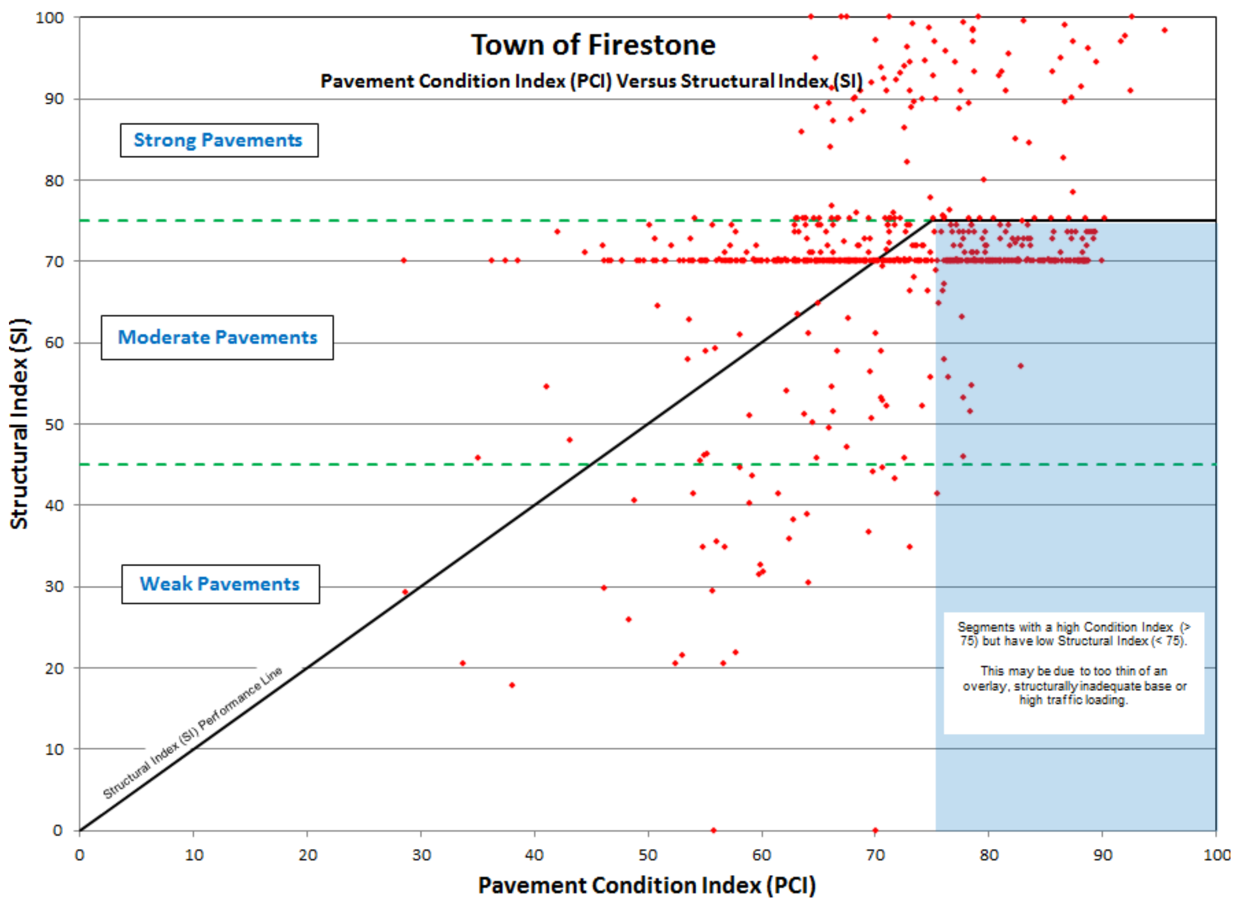

Figure 9 – Structural Adequacy of the Arterial and Collector Roadway Network

Figure 9 presents the structural adequacy of the arterial and collector roadway network against its average pavement condition, with each marker representing one segment of roadway. The diagonal black line in the plot provides an indication of roadway segments that are performing above structural expectations and those that do not provide full structural benefits over the life of the pavement.

Areas of concern are the street segments falling within the shaded blue box. These represent street segments that have a high pavement condition score (greater than 75), yet exhibit low structural characteristics (weak to moderate pavement strengths). When an overlay is to be applied, project level testing and design should be completed to ensure their structural integrity is restored.

The horizontal green dashed lines highlight the Structural Index ranges used as selection criteria during the budget analysis. The structural adequacy of a road is expressed as a 0 to 100 score with several key ranges: roadways with a Structural Index greater than 75 are deemed to be structurally adequate for the loading and may be treated with lightweight surface treatments or thin overlays; those between 45 and 75 typically reflect roads that require additional pavement thickness; and scores below 45 typically require reconstruction and/or increased base and pavement thickness. It should be noted that two segments can have similar PCI values yet have differing subgrade ratings based on their testing results. Once they enter the rehabilitation planning, the Structural Index value would also ensure a thicker overlay or additional localized repairs are applied to the street segment with the lower SI score.

2.4 NETWORK SUMMARY BY FUNCTIONAL CLASSIFICATION

The following table presents the condition scores by pavement type and functional class at the time of the survey. Also included are the surface distress and roughness indices.

Network Summary by Functional Class

	Pavetype	Network	ART	COL	LOC
Segment (Block) Count	All Streets	608	120	109	379
	Asphalt	600	113	109	378
	Concrete	8	7	0	1
Length (mi)	All Streets	59.6	18.6	7.7	33.3
	Asphalt	58.8	17.9	7.7	33.2
	Concrete	0.7	0.7	0.0	0.1
Pavement Condition Index (PCI)	All Streets	71	71	70	71
	Asphalt	71	69	70	71
	Concrete	91	92	0	76
Surface Distress Index (SDI)	All Streets	70	62	73	74
Roughness Index (RI)	All Streets	72	81	68	67
Structural Index (SI)	All Streets	72	78	65	70

2.5 RECONSTRUCTION BACKLOG

Backlog roadways are those that have dropped sufficiently in quality to the point where surface based rehabilitation efforts would no longer prove to be cost efficient. These roadways are rated poor or very poor and will require either partial or total reconstruction. Backlog is expressed as the percentage of roads requiring reconstruction as compared to the network totals.

The concept of Pavement Condition Index (PCI) score and backlog must be fully understood in order to develop an effective pavement management program. The PCI score indicates the overall pavement condition and represents the amount of equity in the system; it is the value most commonly considered when gauging the overall quality of a roadway network. It may also be used to define a desired level of service - that is, an agency may wish to develop a pavement management program such that in five years the overall network score meets a set minimum value. It is the backlog, however, that defines the amount of work an agency is facing and is willing to accept in the future. Furthermore, it is the combination of the two that presents the true picture of the condition of a roadway network, and conversely defines improvement goals.

With the Town of Firestone's average PCI at 71 (now 70) and the reconstruction backlog as low as 1%, the Town's short-term objectives need to focus on not letting this backlog percentage increase. The current rehabilitation program should focus on the pavement network to arrest any potential PCI slide, followed by an aggressive preventative maintenance program focused on lighter weight rehabilitations.

Generally, a backlog of 10% to 15% of the overall network is considered manageable from a funding point of view. Backlogs approaching 20% and above tend to become unmanageable unless aggressively checked through larger rehabilitation programs. For cities such as Firestone with an impressive backlog, it is important that this value be adequately maintained. It is far more costly to let the backlog amount increase further and then attempt to reduce it later than to maintain its current state.

3.0 REHABILITATION PLAN AND BUDGET DEVELOPMENT

3.1 KEY ANALYSIS SET POINTS

Pavement management systems (PMS) require user inputs in order to complete its condition forecasting and prioritization. The existing PMS operating parameters were reviewed in order to develop an efficient program that is tailored to the Town's needs. Some of the highlights include:

- The pavement performance curves that are used to predict future pavement condition reflect the recent work done on the system through the introduction of strength rating – as streets are upgraded, the ratio of pavement condition to load associated distresses improves and the street performs better for longer periods of time. Asphalt streets are classified as weak, moderate or strong, and then assigned the appropriate pavement performance curve to use in the analysis. The concept of load associated distresses does not apply to concrete streets.
- The shape of performance curves reflect the concept of deferred maintenance and salvage life. Instead of dropping to an absolute PCI value of 0 after 40 years of service, the curves are designed to become asymptotic to the age axis and have a whole life of approximately 50 to 75 years depending on pavement type. This indicates the concept that once a street deteriorates past a specific threshold – about a PCI of 20, age becomes less important in rehab selection.
- Priority ranking – the Lucity application utilizes the concept of Priority Weighting Factor (PWF) for rehab candidate selection. It is designed to capture as many segments in the need year based on the incremental cost of deferral.

Pavement Performance Curves

The basic shape of the asphalt performance curves follows traditional sigmoidal deterioration models such as those contained in MicroPAVER and other commonly used pavement management applications. The curves are constructed such that a typical overlay following new pavement construction does not occur until 20 to 30 years have passed, and full reconstruction does not occur until 40 to 60 years have passed or the street has a PCI below 10. Each street is assigned a curve based on its pavement type, functional classification, and pavement strength as determined in Section 2. The curves assume an ultimate life between 75 and 100 years and are designed to be asymptotic to the X-axis (Time) to reflect the salvage value of the pavement once it has reached the end of its service life with a PCI less than 10.

It is important to recognize that even though all streets fall into specific rating categories (as highlighted by the horizontal black dotted lines in Figure 11) and their respective rehabilitation strategies, it is not until a street falls to within a few points of the lower end of the range that it will become a critical need selected for rehabilitation.

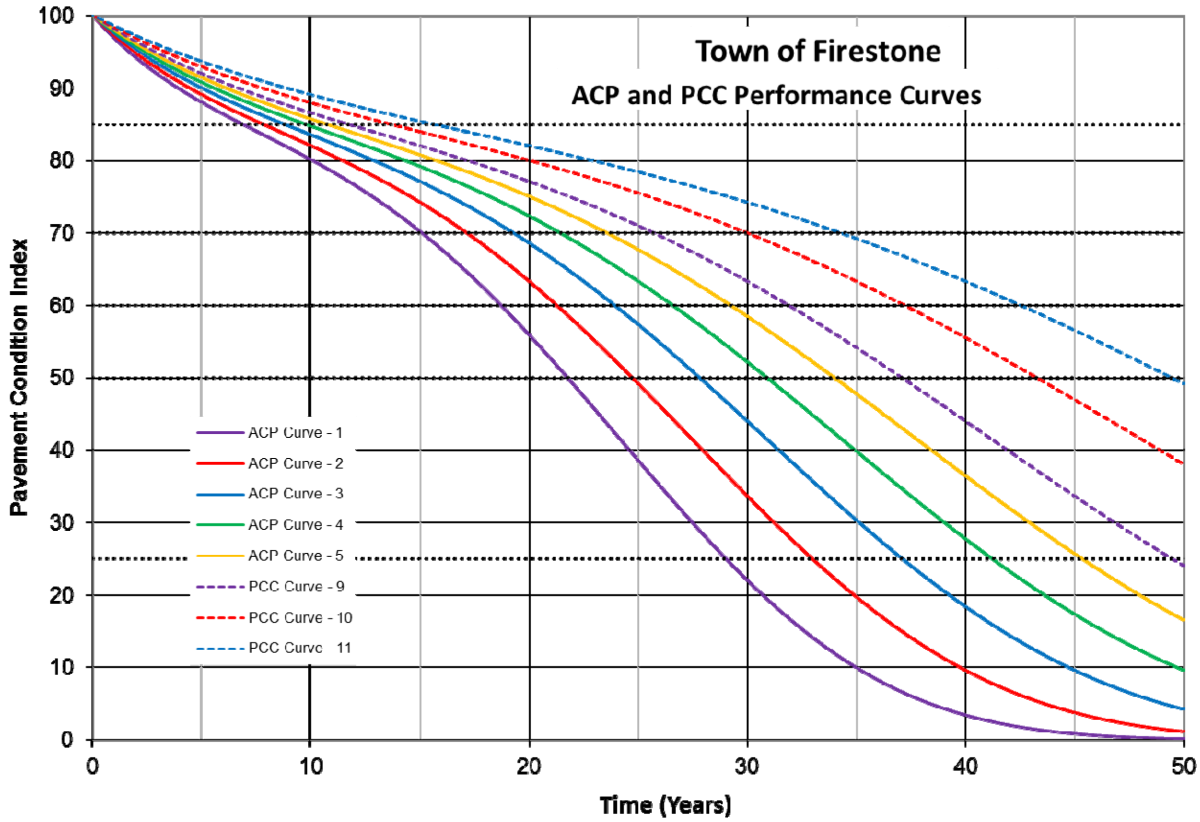

Figure 11 – Asphalt (ACP) and Concrete (PCC) Performance Curves

Rehabilitation Strategies and Unit Rates

The rehab strategies and unit rates used in the pavement analysis can be found in the table below. Some important parameters include:

- **Rehab Activity** – the assigned name to each rehabilitation strategy. The term "RR" refers to remove and replace – that is, structural patching. When this term is present, additional funds have been assigned to the strategy to allow for an increased amount of preparation work and patching. The relative terms of thin, moderate and thick are used to describe the overlay thickness. This is to facilitate consistency in the naming convention, but does not imply the same material thickness has to be used for each functional classification.

- **Unit Rates** – the rehab costs are presented on a per square yard basis for each pavement type, functional class, and rehab activity combination. The rates were developed using typical national averages for similar activities and adjusted for Firestone's location and unique conditions. Rates include a 20% burden for miscellaneous activities (such as striping removal or loop detector replacement), traffic control and engineering inspection. No money has been set aside for contingency, ADA compliance or Town overheads.

- **Min PCI, Critical PCI, Max PCI, Min & Max Structural, PCI Reset** - defines the Pavement Condition Index (PCI) range applicable to the rehab selection, as well as the Structural Index range.

The Critical PCI defines when a segment is in its need year and is deemed to be critical, otherwise if deferred, the street declines in PCI past the point which the rehabilitation is no longer appropriate. PCI Reset is the applied Post-Rehab PCI.

Pavetype	Rehab Code	Rehab Activity	Min PCI	B/P PCI	Max PCI	ART Unit Rate ($/yd2)	COL Unit Rate ($/yd2)	LOC Unit Rate ($/yd2)	Contingency (%)	Traffic Control (%)	Administration (%)	Eng & Inspctn (%)	Reset PCI
	0	Do Nothing				0.00	0.00	0.00	0.0	0.0	0.0	0.0	100
Asphalt	10	Slurry Seal	80	82	85	2.51	2.09	1.90	5.0	5.0	0.0	10.0	88
Asphalt	20	Surface Treatment	70	72	80	3.70	3.09	2.80	5.0	5.0	0.0	10.0	90
Asphalt	23	Surface Treatment + RR	70	72	80	3.95	3.34	3.05	5.0	5.0	0.0	10.0	90
Asphalt	26	Surface Treatment + RR	60	62	70	3.95	3.34	3.05	5.0	5.0	0.0	10.0	90
Asphalt	30	Thin Overlay (1.5 - 2.0)	60	62	70	18.52	15.44	14.00	5.0	5.0	0.0	10.0	92
Asphalt	33	Thin Overlay + RR	60	62	70	19.27	16.19	14.75	5.0	5.0	0.0	10.0	92
Asphalt	36	Thin Overlay + RR	50	53	60	19.27	16.19	14.75	5.0	5.0	0.0	10.0	92
Asphalt	40	Moderate Overlay (1.5 - 3.0)	50	53	60	22.15	18.47	16.75	5.0	5.0	0.0	10.0	94
Asphalt	43	Moderate Overlay + RR	50	53	60	23.15	19.47	17.75	5.0	5.0	0.0	10.0	94
Asphalt	46	Moderate Overlay + RR	40	43	50	23.15	19.47	17.75	5.0	5.0	0.0	10.0	94
Asphalt	50	Thick Overlay (> 2.0 - 3.0)	40	43	50	27.77	23.15	21.00	5.0	5.0	0.0	10.0	96
Asphalt	53	Thick Overlay + RR	40	43	50	29.02	24.40	22.25	5.0	5.0	0.0	10.0	96
Asphalt	56	Thick Overlay + RR	25	30	40	29.02	24.40	22.25	5.0	5.0	0.0	10.0	96
Asphalt	60	Surface Reconstruction	25	30	40	56.27	42.83	37.00	5.0	5.0	0.0	10.0	98
Asphalt	70	Full Recon / Surface Recon	0	15	25	68.44	52.09	45.00	5.0	5.0	0.0	10.0	100
Concrete	510	PCC Joint & Crack Sealing	80	82	85	1.00	1.00	0.90	5.0	5.0	0.0	10.0	88
Concrete	520	PCC Localized Rehab	70	72	80	2.40	2.20	2.00	5.0	5.0	0.0	10.0	90
Concrete	530	PCC Slight Pnl Rplcmnt	60	62	70	11.50	10.50	9.50	5.0	5.0	0.0	10.0	92
Concrete	540	PCC Moderate Pnl Rplcmnt	50	53	60	14.75	13.50	12.25	5.0	5.0	0.0	10.0	94
Concrete	550	PCC Extensive Pnl Rplcmnt	40	43	50	28.00	25.50	23.00	5.0	5.0	0.0	10.0	96
Concrete	560	Partial PCC Recon	25	28	40	98.50	100.50	91.50	5.0	5.0	0.0	10.0	98
Concrete	570	Full PCC Reconstruction	0	15	25	147.00	134.00	122.00	5.0	5.0	0.0	10.0	100

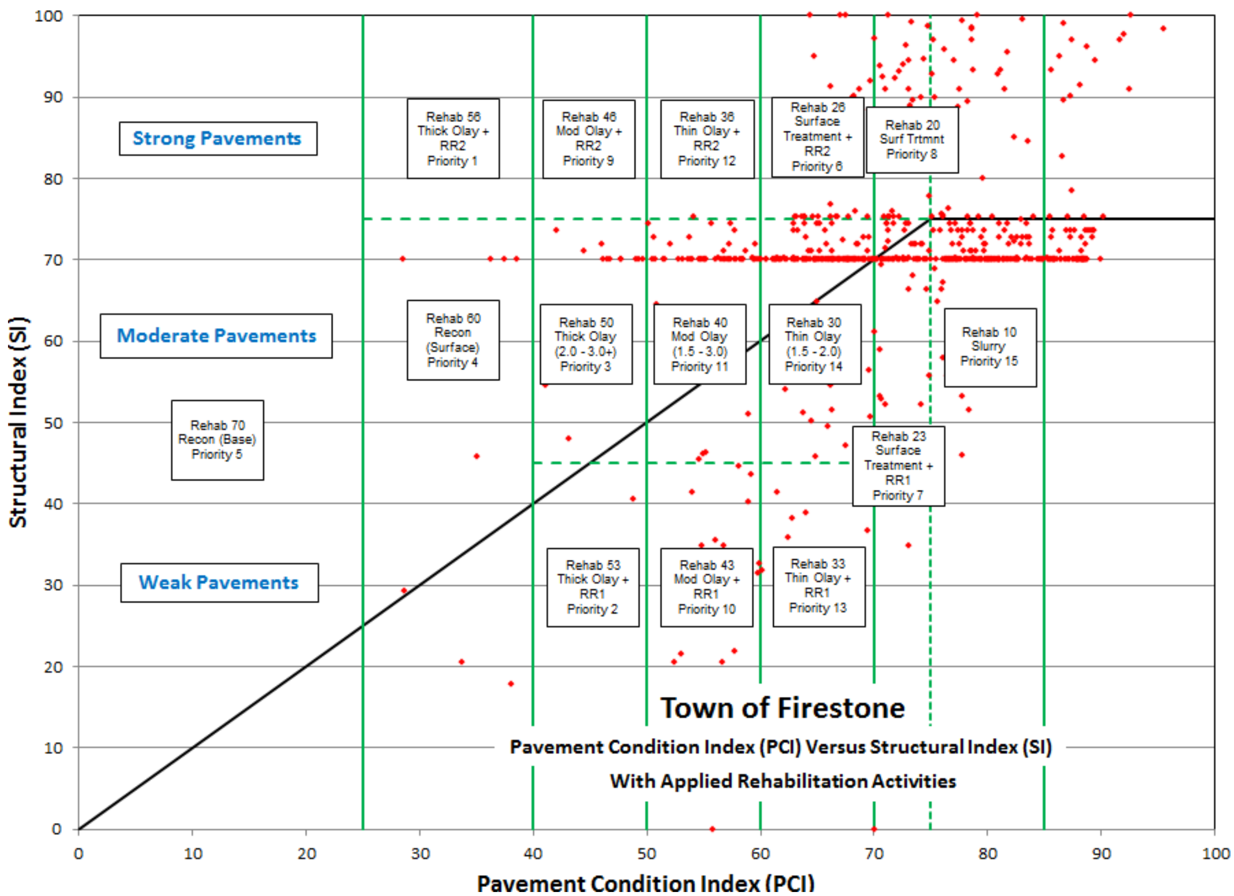

Figure 12 – Asphalt (ACP) Rehabilitation Strategies

Figure 12 graphically presents the application of pavement rehabilitations for asphalt streets by PCI and Structural Index of the roadway network. The Rehab number are simply a placeholder to separate one rehabilitation from another (for example Rehab 43 is a Moderate Overlay with RR).

Priority Weighting Factor (PWF)

The town's pavement management program incorporates a user defined value, referred to as the Priority Weighting Factor (PWF), to prioritize the street segments for rehabilitation selection. The rehab selection order is not worst first, but rather designed to capture as many segments in the need year based on the incremental cost of deferral. Coupled with the rehabilitation sequence, the priority weighting factor defines the order in which streets are selected for rehabilitation. The streets are lined up in order of priority then the software applies the various rehabilitation strategies in order of sequence starting with the critical roadways, followed by none-critical roadways pending available funding. The effect of these two settings is to develop the most cost effective rehabilitation plan that maximizes pavement life before applying rehabilitation. Applied at the project or supersegment level, Priority = (100 – PCI) x PWF and has a scale ranging from 0 to 10, and is initially calculated for all projects.

The priority weighting factor for Firestone is threefold in nature. The assigned PWF follows functional classification (the more important the street, the higher PWF), followed by strength. Weak streets are assigned a slightly higher PWF over moderate and strong as they deteriorate at a higher rate. The following table illustrates the PWF values assigned to each segment based on functional class and pavement type:

FunCL	Asphalt Weak	Asphalt Moderate	Asphalt Strong	Concrete Weak	Concrete Moderate	Concrete Strong
Arterial	100	95	90	90	85	80
Collector	90	85	80	80	75	70
Local	75	70	65	65	60	55

3.2 FIX ALL AND ANNUAL ESTIMATES

Three different approaches may be taken to identify and confirm the amount of funds the Town needs to set aside each year to maintain the roadway network at its current condition. All three are completed externally to the pavement management system and are simply used to validate the final results.

Option 1 – Estimated Life Cycle Cost Based on Network Value

A ballpark value for the annual street maintenance budget may be quickly determined by taking the total value of Firestone's roadway network, estimated at $51M, and dividing that by the ultimate life of a roadway – assumed to be 75 to 100 years for asphalt and concrete respectively (please note, the 75 to 100 year lifespan of the roadway is the theoretical life of the road from construction, until the point at which there is nothing left but the right of way, it is not simply the lifespan of the pavement surface). By this method, the annual budget is estimated at $680K.

Pavement Type	Pavement Value ($)	Ultimate Life Span (yrs)	Life Cycle Annual Cost ($/yr)
Asphalt Network	48,399,000	75	650,000
Concrete Network	2,796,000	100	30,000
All Streets	**51,195,000**		**680,000**

Option 2 – Estimated Life Cycle Cost Based on Current Condition

A second method to validate the annual budget is to identify the average network PCI and associated rehabilitation requirements, and then estimate the number of miles required to be rehabilitated each year based on a typical life cycle for that rehabilitation activity. For Firestone, the average PCI for asphalt roads is 71 and 91 for concrete roads, placing Firestone in the surface treatment and routine maintenance range. At an average cost of $2.40/yd^2 for surface treatment, and $0.30/yd^2 for localized rehab on concrete streets, the Town needs to spend approximately $290K/year to maintain the current condition average.

Pavement Type	Pavement Condition Index (PCI)	Typical Rehab Based on Condition	Blended Rehab Unit Rate ($/yd2)	Average Rehab Life Cycle (yrs)	Miles To Do Each Year (mi)	Cost Per Mile ($/mi)	Life Cycle Annual Cost ($/yr)
Asphalt Network	71	Surface Treatment	2.4	10	5.9	50,000	290,000
Concrete Network	91	Routine Maintenance	0.30	2	0.4	10,000	0
All Streets							**290,000**

Option 3 - Estimated Life Cycle Cost Based on Network Deficiency

The third methodology to confirm the required amount of annual funding is to identify the current network deficiency, that is the amount required to rehabilitate all streets in the network assuming unlimited funding, and then divide by the typical life cycle of each rehabilitation activity. This is referred to as the Fix All Estimate and Life Cycle Cost. The rehab strategies listed in the table are generic in nature and not necessarily the final set that was applied to Firestone. For Firestone, the Fix All Estimate for the network deficiency is approximately $9 million and the Life Cycle Cost is $571K/year, broken down as follows:

Asphalt Deficiency	Total Cost ($)	% of Total	ART	COL	LOC	Life Cycle (years)	Life Cycle Cost ($)
Reconstruction (Base)	0	0.0	0	0	0	50	0
Reconstruction (Surface)	665,300	7.5	0	256,000	409,300	35	19,000
Thick Overlay	674,500	7.6	379,700	24,300	270,500	25	27,000
Moderate Overlay	2,204,700	24.8	979,500	324,500	900,700	20	110,000
Thin Overlay	4,144,900	46.6	1,444,900	601,500	2,098,500	20	207,000
Surface Treatment	486,400	5.5	263,500	56,000	166,900	10	49,000
Slurry Seal	692,200	7.8	203,900	85,200	403,100	5	138,000
Routine Maintenance	33,400	0.4	7,100	3,800	22,500	2	17,000
Total Asphalt Network:	**8,901,400**	**100**	**3,278,600**	**1,351,300**	**4,271,500**		**567,000**
Concrete Deficiency	**Total Cost ($)**	**% of Total**	**ART**	**COL**	**LOC**	**Life Cycle (years)**	**Life Cycle Cost ($)**
PCC Reconstruction	0	0.0	0	0	0	75	0
PCC Partial Recon	0	0.0	0	0	0	50	0
Extensive Pnl Rplcmnt	0	0.0	0	0	0	25	0
Moderate Pnl Rplcmnt	0	0.0	0	0	0	20	0
Slight Pnl Rplcmnt	0	0.0	0	0	0	20	0
Localized Rehab	0	0.0	0	0	0	10	0
Crack Sealing	3,700	38.1	3,000	0	700	5	1,000
Routine Maintenance	6,000	61.9	6,000	0	0	2	3,000
Total Concrete Network:	**9,700**	**100**	**9,000**	**0**	**700**		**4,000**
Total Network :	**8,911,100**		**3,287,600**	**1,351,300**	**4,272,200**		**571,000**

3.3 NETWORK BUDGET ANALYSIS MODELS

An analysis containing a total of 3 budget runs ($200K, $640K, and $1M per year) plus Unlimited and Do Nothing options was prepared for the Town of Firestone. The analysis results are summarized below:

- **Unlimited -** The Unlimited (or Fix All) budget assumes each street is rehabilitated with unlimited funds available. The idea is to identify the upper limit of spending the Town would require without any constraints on budgets. For Firestone, the unlimited budget is approximately $9 million over 5 years and increases the network PCI to a maximum of 91 tapering off to an 88 within 5 years.
- **Do Nothing -** This option identifies the effect of spending no capital for 5 years. After 5 years, the Do Nothing option results in a PCI drop from a 71 to a 61.
- **$200K through $1M -** Identifies the resultant network PCI at various funding levels. The $640K analysis represents the steady state budget.

The results of the analysis are summarized in Figure 13 below. The X axis highlights the annual budget, while the Y axis plots the 5 Year Post Rehab PCI value. The diagonal blue line is the analysis results. As can be seen from the plot, a budget of $640K per year would maintain the network at its current PCI of 70.

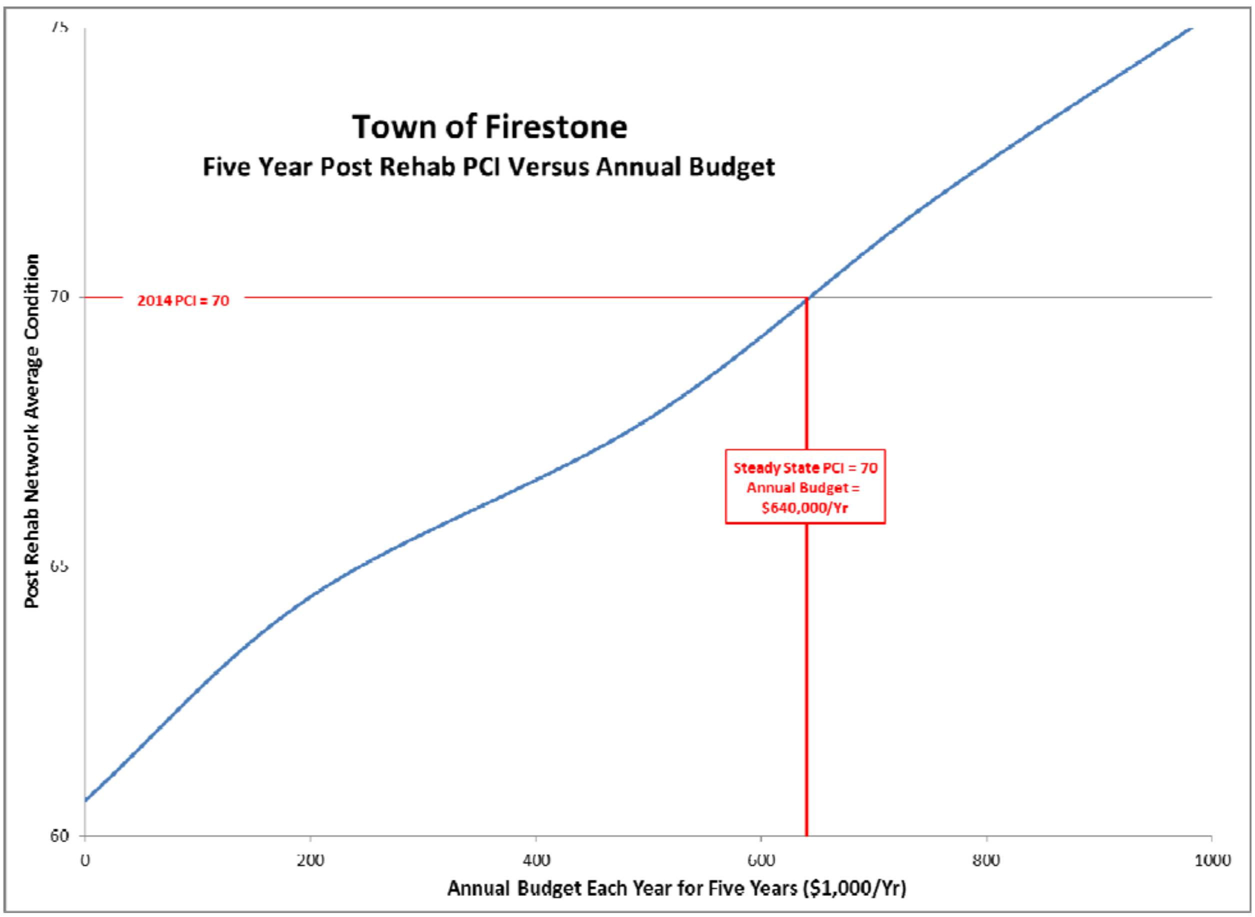

Figure 13 – 5 Year Network PCI Analysis Results

Figure 14 below presents the same analysis results on an annual basis. This shows that if the budget falls below $640K per year, over time, the overall condition of the roads will deteriorate as the backlog increases.

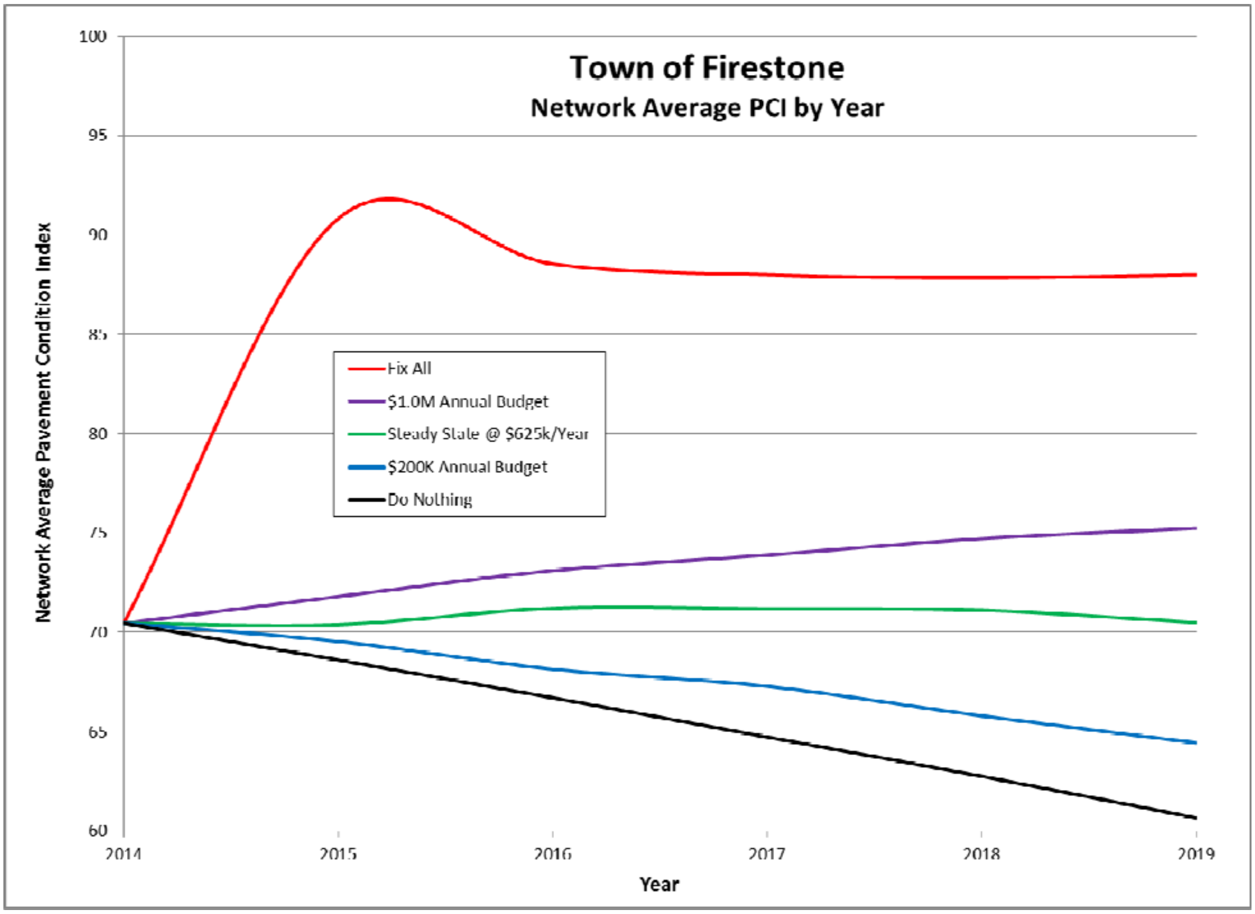

Figure 14 – 5 Year Annual PCI

3.4 FIRESTONE COMPARISON TO OTHER AGENCIES

The following table presents the steady state versus actual funding levels of various agencies that use similar reporting and analysis software. The list is by no means representing all agencies that use a pavement management system, but rather is a sampling of what other agencies are doing.

Network Funding Comparison

Agency	State	Year	Mileage (mi)	PCI	Backlog	Steady State Budget ($M/yr)	Steady State Rate ($/mi)	Actual Funding ($M/yr)	Comments
Agency CB	CA	2010	334	81	2%	$3.40	$10,000	$3.40	Fully funded
Agency FW	WA	2011	231	79	4%	$2.25	$10,000	$2.25	Fully funded, well structured
Agency E	TX	2014	128	77	2%	$0.80	$6,000	$0.80	Slightly underfunded, excellent backlog
Agency MF	OR	2013	270	77	3%	$3.00	$11,000	$2.25	Slightly underfunded, very low backlog
Agency L	NE	2012	338	77	9%	$5.25	$16,000	$5.00	Slightly underfunded, majors only
Agency K	TX	2010	189	76	9%	$1.50	$8,000	$1.50	Fully funded
Agency B	SD	2014	40	76	4%	$0.35	$9,000	$0.35	Excellent Backlog
Agency CG	AZ	2010	310	76	4%	$3.00	$10,000	$2.00	Underfunded
Agency ST	WA	2011	80	76	4%	$0.90	$11,000	$2.25	Fully funded, well structured
Agency LM	CA	2010	141	76	12%	$2.40	$17,000	$2.00	Slightly underfunded
Agency GI	NE	2013	284	74	1%	$2.50	$9,000	$3.00	Fully funded
Agency FS	CO	2014	60	71	1%	$0.64	$11,000	$0.20	Underfunded, but solid backlog and PCI
Agency FT	CA	2013	497	73	7%	$6.50	$13,000	$6.50	Fully funded, well structured
Agency F	ND	2012	438	72	9%	$6.00	$14,000	$4.00	Underfunded
Agency SS	GA	2012	311	72	10%	$4.75	$15,000	$3.20	Underfunded, does not do surface treatments
Agency GD	AZ	2009	718	71	4%	$15.00	$21,000	$2.00	Underfunded and struggling
Agency H	KS	2010	120	70	4%	$0.85	$7,000	$0.50	Underfunded
Agency DW	GA	2009	147	69	14%	$2.75	$19,000	$2.75	Fully funded
Agency SV	WA	2013	439	68	9%	$7.25	$17,000	$2.00	Underfunded, but solid backlog
Agency Y	CA	2011	200	68	5%	$1.60	$8,000	$1.00	Underfunded, decreasing PCI
Agency CY	WY	2010	332	68	4%	$2.50	$8,000	$2.50	Fully funded
Agency TC	TX	2010	1270	68	7%	$11.00	$9,000	$8.00	Underfunded
Agency LV	WA	2011	138	68	7%	$2.80	$20,000	$0.55	Underfunded - looking for alternate funding
Agency DL	CA	2010	578	68	14%	$18.50	$32,000	$8.50	Very high unit rates for providing a high LOS
Agency LA	NM	2010	106	67	11%	$1.50	$14,000	$1.50	Fully funded and working to increase PCI
Agency WF	TX	2012	170	66	15%	$1.40	$8,000	$0.66	Underfunded
Agency C	CA	2011	56	66	12%	$1.10	$20,000	$1.10	Fully funded
Agency L	CO	2014	160	66	15%	$2.30	$14,000	$2.30	Backlog a concern
Agency BV	OK	2012	152	65	11%	$1.25	$8,000	$1.25	Fully funded and working to increase PCI
Agency KW	FL	2012	65	65	7%	$0.75	$12,000	$0.75	Fully funded
Agency C	CO	2012	443	64	12%	$6.00	$14,000	$5.00	Slightly underfunded
Agency LC	NM	2012	455	63	17%	$5.60	$12,000	$3.00	Underfunded and concerned about backlog
Agency D	TX	2010	436	61	16%	$10.00	$23,000	$3.20	Extremely underfunded and passing a bond
Agency V	CA	2012	472	60	14%	$7.50	$16,000	$2.50	Underfunded and concerned about backlog
Agency LB	CA	2014	786	60	20%	$26.50	$34,000	$17.50	Severely Underfunded
Agency LC	PA	2012	102	59	15%	$1.00	$10,000	$0.75	Underfunded
						Average:	**$15,000**		

In comparison to other agencies, Firestone's steady state budget requirement of approximately $11,000/mile is slightly below the national average of $15,000. This is consistent with its PCI score being in the low 70's. However, this does not account for the backlog, which would increase at the steady state budget. In order for the backlog to remain steady at current levels, the budget needs to be higher than $640K a year.

3.5 NETWORK RECOMMENDATIONS AND COMMENTS

The following recommendations are presented to the Town of Firestone as an output from the pavement analysis, and must be read in conjunction with the attached reports.

1. The Town should adopt a policy statement identifying the desired level of service and acceptable amount of backlog. We suggest a target that maintains the current network profile at or above a PCI of 70 for 5 years, while keeping the backlog well below 10% (anything below 5% is difficult to achieve – so a slight increase is not a worry).

   An annual budget of at least $640k is required to achieve this goal. The average network PCI would hold steady at and the backlog would remain below 5%. The total 5 year cost of this alternative is $3.2M.

2. The full suite of proposed rehabilitation strategies and unit rates should be reviewed annually as these can have considerable effects on the final program.
3. All unit rates include a 20% burden in addition to their actual construction cost to cover traffic control, miscellaneous activities, and inspection. The unit rates have no funding for ADA compliance as these are assumed to be funded separately.
4. All costs are in constant 2014 dollars. No allowances have been made for inflation or fluctuations in rehabilitation costs.
5. No allowance has been made for network growth or conversion of gravel roadways to pavement. As the Town expands or increases the amount of paved roads, increased budgets will be required.
6. No allowance has been made for routine maintenance activities such as asphalt crack sealing, sweeping, striping or patching within the budget runs and analysis. These costs are assumed to be outside the pavement management costs.
7. The Town should resurvey their streets every few years to update the condition data and rehabilitation program.